BIOLOGY AND PHENOLOGY OF GIANT GRASSHOPPER, *VALANGA IRREGULARIS* (WALKER) (ORTHOPTERA: ACRIDIDAE: CRYTACANTHACRIDINAE), A PEST OF CITRUS, IN CENTRAL WESTERN NEW SOUTH WALES

S.V. RAJAKULENDRAN[1], R. PIGOTT[2] and G.L. BAKER[1]

[1] *Biological and Chemical Research Institute, NSW Agriculture, P.M.B. 10, Rydalmere, N.S.W. 2116*

[2] *NSW Agriculture, P.O. Box 865, Dubbo, N.S.W. 2830*

Abstract

A study of giant grasshopper, *Valanga irregularis*, infesting an orange (*Citrus sinensis* (L.) Osbeck) orchard at Coonamble [30°58'S 148°22'E] in central western New South Wales showed the population was univoltine: eggs laid in early spring hatched in late spring and early summer and nymphs fledged in early autumn; adult females remained in reproductive dormancy from autumn to mid winter and became sexually mature in late winter. No parasitoids were reared from field collected nymphs or adults, but the egg parasitoid *Scelio flavicornis* Dodd (Hymenoptera: Scelionidae) was reared from 16.6 per cent of field collected egg pods.

Laboratory reared nymphs developed through 7 instars. At 27°C the mean nymphal development time was 112.5 d ± SE 3.2.

Phenology and feeding behaviour indicate that control of nymphs in late summer (February) is appropriate.

Introduction

The endemic giant grasshopper, *Valanga irregularis*, the largest acridid species in Australia (Key 1970), occurs throughout the northern and eastern coastal, sub-coastal and adjoining semi-arid zones of the Australian mainland from the Kimberley district of Western Australia to the south coast of New South Wales (COPR 1982, R. Elder, Dept. Prim. Ind., Rockhampton, *pers. comm.*). It is known to feed on cotton, wheat, maize, grain sorghum, tomato (Anon. 1951), carrot, banana (unpublished data Entomology Branch, NSW Agriculture), grapevines and citrus (Hely *et al.* 1982). In New South Wales damage to citrus in home gardens has occurred on North Western Slopes and Plains and Central Western Slopes and Plains (Hely *et al.* 1982) and in commercial orchards at Nyngan and Coonamble on the Central Western Plain in 1989-1990 (Rajakulendran 1990) and at Tamworth on the North West Slope in 1992 (R. Holtkamp, NSW Agric., Tamworth, *pers. comm.*).

Except for White's (1968) study of adult polymorphism, there is no published information on the biology or phenology of *V. irregularis* and this study was undertaken to gain a knowledge of the phenology necessary for the efficient timing of insecticide applications.

Methods and materials

Field studies on phenology

Adult and nymphal development were studied in a population in an orchard at Coonamble [30°58'S, 148°22'E] on the North Central Western Plain with a recent history of damaging infestations of *V. irregularis*. The orchard consisted of 12.5 ha of 40 year old Valencia and navel orange (*Citrus*

Table 1. Average monthly mean daily maximum and minimum temperature and average monthly rainfall at Coonamble (Bureau of Meteorology)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec
Temperature												
Max. °C	35.0	34.0	31.6	26.7	21.9	18.0	17.0	19.3	23.4	27.6	31.2	34.0
Min. °C	19.0	18.7	16.3	11.6	7.7	4.9	3.6	4.5	7.2	11.4	15.0	17.7
Rainfall												
(mm)	84.5	50.4	40.1	36	54.1	28	35.1	37.4	32.2	48.1	38.5	46.2

sinensis) trees on a 5 m (interrow) and 7 m (row) spacing with 3 year old replacement plantings at the same density. Irrigation was by undertree sprinklers. Interrow areas were maintained by regular slashing of mixed grasses and weeds. The climatic characteristics of the study site are given in Table 1.

Approximately 20 adult females were hand-picked from trees monthly from September 1989 until October 1990 and transferred to the laboratory to determine their body weight, ovary weight and ovariole number. Nymphs were sweep netted from ground cover and also shaken off branches into a net each month between mid December 1990 and April 1991. The proportion of each instar in samples was determined in the laboratory using criteria derived from laboratory studies of nymphal development. Field collected eggs were held in the laboratory for the emergence of parasitoids.

Laboratory development of eggs and nymphs

Eggs were obtained by placing field collected sexually mature females and males in clear perspex cages (40 x 55 x 38 cm) over sand filled pots. Eggs laid in the pots were held at 25°C until hatching ceased. The sand was kept moist during incubation.

Nymphs were either mass reared or held in low numbers per cage in a constant environmental chamber (Thomson®) maintained at 27 ± 1°C (average mid-summer temperature in field: Table 1), 70 ± 5% RH and 12 h photophase. Those mass reared were held in clear perspex cylinders (9.5 cm dia. x 16 cm) sealed at each end by perforated aluminium sheets. All nymphs which hatched synchronously were placed in a single cage (approximately 50 per cage) for studies on total development time. Nymphs reared in low numbers per cage (<5) were kept in clear plastic cylinders (3.5 cm dia. x 9 cm) with fine wire mesh bottoms and plastic cap tops for detailed observations on the number of instars and the duration of each instar. Fresh immature orange foliage in a glass vial filled with water was provided every 3 days. For both groups, the instar of each nymph and the presence of exuvia were recorded at the time of changing the food.

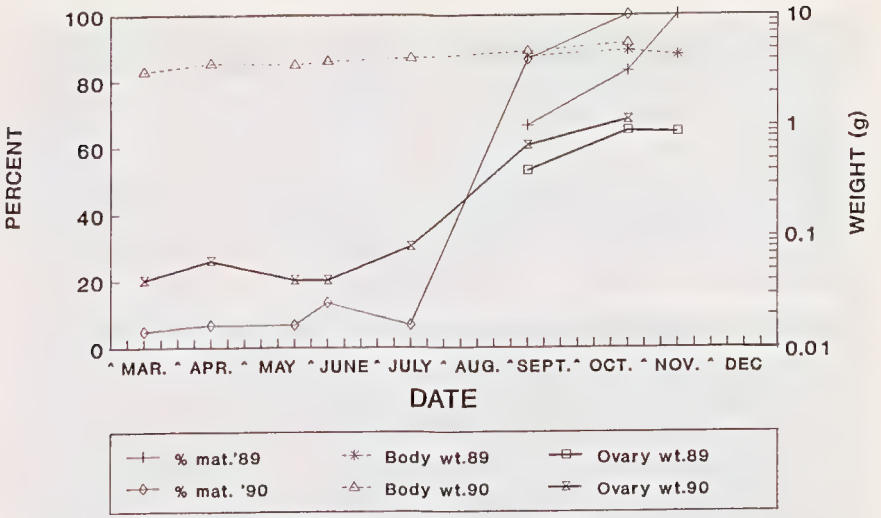


Fig. 1. Maturation of female *Valanga irregularis* in the field. Data on per cent mature, mean body weight and mean ovary weight presented for spring 1989 and autumn/ winter/ spring 1990. Body weight and ovary weight are plotted on log scale.

Nymphal morphometric data were obtained for 10 randomly selected specimens (instars 1-4) and for five males and five females (instars >4). Head capsule width and femur length were measured using a stereomicroscope fitted with a graticule after the method of Uvarov (1966).

Results

Field studies

Maturation of females (Fig. 1): Mean body weight increased slowly between March and June 1990, with no apparent change in mean ovary weight. Between June and September 1990 mean body weight increased x1.256 (3.8 to 4.79 g) and mean ovary weight increased x16.5 (0.04 to 0.66 g) and both peaked in October (5.57 g and 1.13 g respectively).

Sexual maturation (indicated by the development of oocyte yolk) began in late winter (August) and was completed by mid spring (October). Females which had oviposited (indicated by the presence of laying bodies) and gravid females were first recorded in late October in both 1989 and 1990. Oviposition was not observed during the day, but two instances were observed after dark (20.00 hr) on 31 October 1990. Egglaying was restricted to beneath the periphery of the canopy where soil moisture was visibly highest. During winter 2 of 81 females dissected were found to have mature oocytes and had previously oviposited being senescent adults from the previous season.

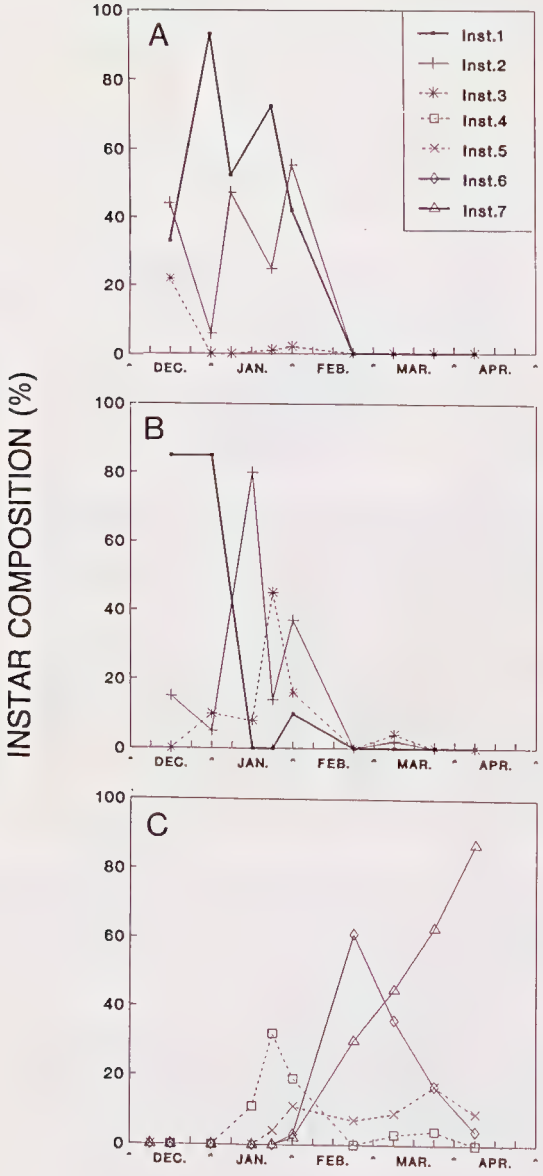
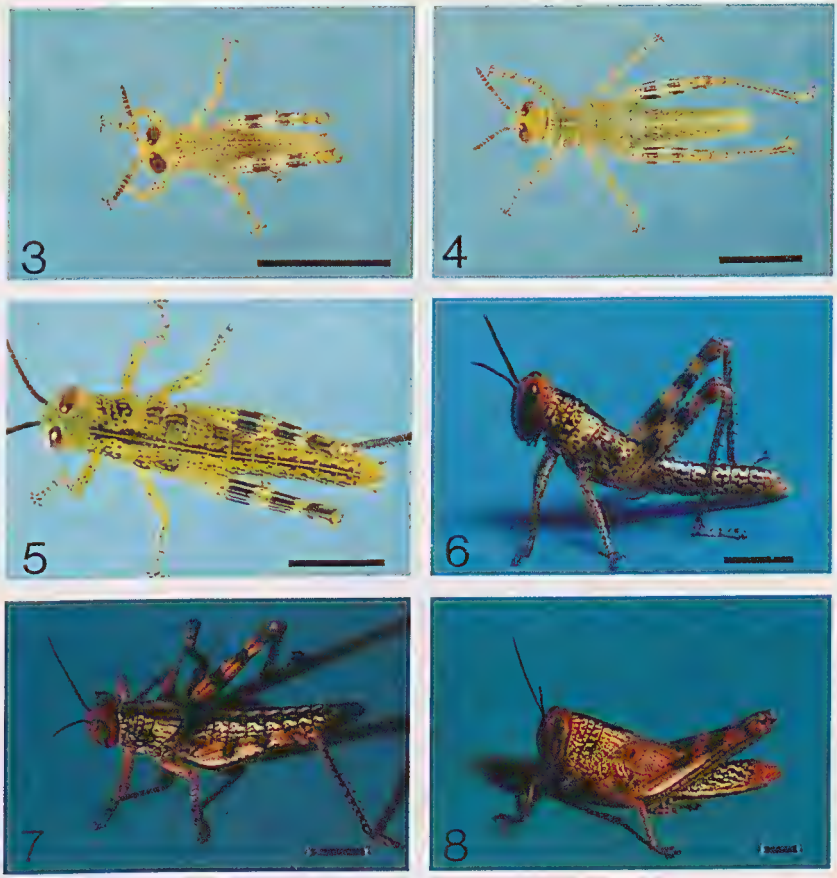


Fig. 2. Percentage instar composition of nymphs of *Valanga irregularis* in a citrus orchard. A, population in ground cover. B, population in trees (instars 1-3). C, population in trees (instars 4-7).



Figs. 3-8. *Valanga irregularis* nymphs. 3, first instar. 4, second instar. 5, third instar. 6, fourth instar ♀ (fifth instar same as fourth except larger). 7, sixth instar ♀. 8, seventh instar ♀. Scale bar = 5 mm.

The number of ovarioles in both ovaries ranged from 145 to 178. The number of laying bodies (Uvarov 1966) indicated a minimum of three ovarian cycles were completed by mid summer (January). There was little resorption of eggs and the number of eggs per pod was equated with the ovariole number.

Parasitism of eggs: Eighteen egg pods were collected in the field in November 1990 and retained in the laboratory for hatching. An egg parasitoid, *Scelio flavicornis* Dodd (Hymenoptera: Scelionidae), emerged from 3 of the pods (16.6%) and parasitised a variable proportion (47, 53 and 80 % respectively) of the eggs in each pod, equivalent to 10% of eggs in the

Table 2. Morphometrics of *V. irregularis* nymphs (n=10 for each instar).

Instar		Head capsule width (mm) x ± SD	Femur length (mm) x ± SD	Body length (mm) x±SD
First		1.57 ± 0.05	4.3 ± 0.2	7.4 ± 0.4
Second		1.98 ± 0.06	5.4 ± 0.3	11.2 ± 0.7
Third		2.78 ± 0.13	8.1 ± 0.3	16.2 ± 1.8
Fourth		2.85 ± 0.15	10.4 ± 0.5	22.8 ± 1.9
Fifth	♂	2.98 ± 0.06	11.0 ± 0.0	24.3 ± 1.0
	♀	3.57 ± 0.12	14.2 ± 1.0	25.8 ± 2.2
Sixth	♂	4.02 ± 0.18	16.0 ± 0.6	31.9 ± 3.0
	♀	5.18 ± 0.33	19.5 ± 0.8	36.9 ± 3.0
Seventh	♂	5.15 ± 0.41	20.1 ± 0.9	40.2 ± 3.1
	♀	6.86 ± 0.32	25.9 ± 1.0	45.4 ± 3.1

field collected pods. This is the first record of a *V. irregularis* egg parasitoid and is the first host record for *S. flavicornis* which was described in 1913 (Dodd 1913).

Egg hatching and nymphal development: Hatching commenced in late spring (mid November) and continued until the mid-summer (late January) in both the 1989 and 1990 seasons. Sweep netting of ground cover in mid-summer (December 1990) revealed the presence of first, second and third instar nymphs (Fig. 2A). Some senescent females persisted throughout autumn, but no oviposition took place after mid-summer (January).

Nymphal development took 80-90 days (mid November-late February).

First and second instar nymphs were collected from ground cover and trees (Fig. 2A), but later instars were consistently found on trees (Fig. 2B) with severe damage evident by mid-summer (January) by third and fourth instar nymphs. Early instar nymphs inhabiting the ground cover fed on the foliage of caltrop, *Tribulus terrestris* L. (Zygophyllaceae) and were not observed feeding on monocotyledons.

The first adults appeared in late summer (25.ii.1991) and fledging was complete by mid autumn (April).

Laboratory studies

Egg and nymphal development: Laboratory laid eggs held at 27°C had an incubation period of 91.5 d SD ± 0.93 (n=5 pods). Hatching of eggs in each pod was completed within 3 d.

Seven nymphal instars were recorded. Their morphometrics are given in Table 2 and a brief description of each follows:

First instar (Fig. 3): very pale on hatching but assuming a light green colour after 3-5 minutes. Head disproportionately large; relatively short, laterally compressed abdomen. Subsequently, light green in colour with black markings on legs. Wingbuds rudimentary.

Second instar Fig. 4): bright green with black markings on both legs and body. Distinct median dorsal stripe from the cervix to last abdominal segment. Head and thorax retain the rectangular appearance of 1st instar nymphs.

Third instar (Fig. 5): bright green with black markings. Head and prothorax much enlarged and in side view appeared more triangular than rectangular. Wing buds prominent, straight and pointing latro-ventrally.

Fourth instar (Fig. 6): pronounced colour change with green background assuming an orange tinge. This change was not observed in the field collected nymphs of the same instar.

Fifth instar: differ from fourth instar in size only. Wingbuds large and remain pointing latero-ventrally. Sexual dimorphism apparent, females being larger than the males.

Sixth instar (Fig. 7): readily distinguished from all previous instars by the reversal of the wing buds (alar rudiments). Males had a mean fore wingbud length of 5.01 mm ±SD 0.451 and females 5.47 mm ±SD 0.41.

Seventh instar (Fig. 8): large and robust, head and thorax taking on appearance of adult. Males had a mean fore wingbud length of 11.35 mm ±SD 0.47 and females 11.35 mm ±SD 0.67.

Laboratory reared and field collected adults did not differ in size, were similarly coloured and exhibited the same colour pattern polymorphism.

Nymphal survival and instar mortality (Fig. 9): Mean mortality of the first instar nymphs, during the first 10 days following hatching was 58.8 ± SD 29.6% (n=5 pods). A rhabditid nematode present in the froth plug of some egg pods also developed in many of the cadavers, but could not be confirmed as the cause of death. Mortality of subsequent instars was relatively low (< 40%).

Duration of nymphal development (Fig. 10): Mass reared nymphs had a shorter development time in all but the third instar than those reared in low numbers. There was no difference in the development time of males and female nymphs except in the final (seventh) instar where the development time of females was almost twice that of males. The total development time (Σ instar mean) in the laboratory at 27°C ranged from 77.5 d (unsexed, mass reared in large cages) to 123.3 d (females in small cages). The development time of mass reared unsexed nymphs is comparable to the 60-80 d from first hatch to instar 7 and last hatch to peak of instar 7 observed in the field (Fig. 2).

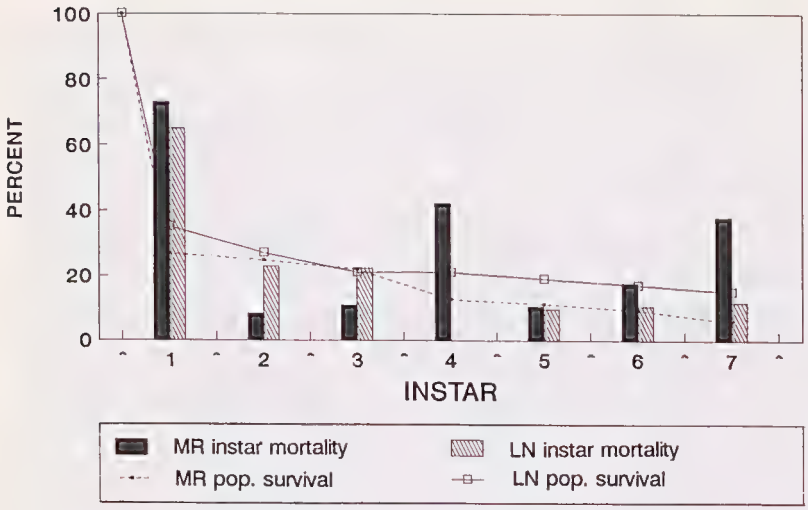


Fig. 9. Population survival and instar mortality of *Valanga irregularis* mass reared (MR) and reared at low numbers per cage (LN) in the laboratory. Bars, mortality during each instar. Lines, progressive survival.

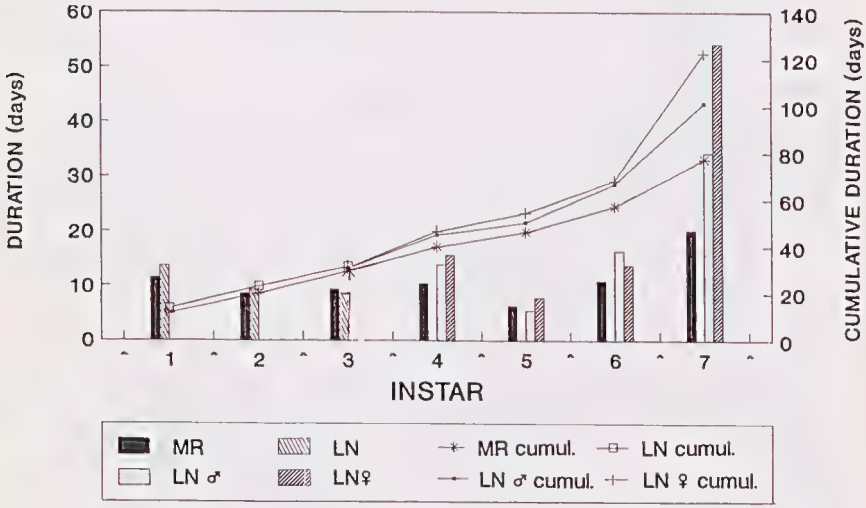


Fig. 10. Development of nymphs of *Valanga irregularis* in the laboratory when mass reared (MR) and reared at low numbers per cage (LN). Bars, duration of each instar. Lines, cumulative duration.

Discussion

The phenology of *V. irregularis* is similar to that described for another crytacanthrid, spur-throated locust, *Nomadacris guttulosa* (Walker), by Farrow (1977), Casimir and Edge (1978) and Elder (1989). The reproductive dormancy of *N. guttulosa* is an adaptation to a seasonally dry monsoonal climate (Elder 1991), whereas *V. irregularis* is widely distributed in coastal and sub-coastal regions where seasonal aridity is infrequent and any adaptive advantage of the reproductive diapause in *V. irregularis* in these regions is not immediately apparent. The suggestion by Sjöstedt (1932) that *V. irregularis* overwinters as eggs is erroneous.

Given the relatively high fecundity of *V. irregularis* and the localised and infrequent nature of outbreaks in citrus orchards, important mortality factors must operate to keep numbers in check. This study identified two possibly important natural mortality factors, egg parasitism by *S. flavicornis* and first instar mortality from an unknown cause. The presence of acceptable plant species in the ground cover may also be a significant factor in first instar nymphal survival.

The rhabditid nematode found in dead, laboratory reared and field collected first instar nymphs, was probably saprozoic, since exposure of live *Galleria mellonella* (L.) (Lepidoptera: Pyralidae) larvae to high density dauer larvae did not result in infection after 10 days exposure (R. Bedding, CSIRO Division of Entomology, Canberra, *pers. comm.*). The nematode was first reared from field collected adult *S. flavicornis* which died after placement with laboratory laid *V. irregularis* eggs on moist sterilised sand. The rhabditid may have a phoretic relationship with *S. flavicornis*, being transported between egg pods by the adult females then breeding in the froth plug and finally completing the cycle by attaching to the next generation of *S. flavicornis* as they emerge.

The phenology of *V. irregularis* provides a long period (March-September) between fledging and oviposition when control could be undertaken, but repetitious defoliation of autumn flush by late instar nymphs and adults is considered by growers to substantially reduce fruit production in the following season. Consequently, it is considered that control should be carried out in late summer (February) after hatching is complete and the nymphs have moved into the trees.

Acknowledgments

The authors would like to thank Dr R. Bedding, CSIRO, Canberra, for investigating the entomopathogenicity of the rhabditid nematode and Dr A. Austin, Waite Agricultural Research Institute, Adelaide, for identifying *S. flavicornis*. Thanks are also extended to Mr R. Williams, Coonamble, on whose property the field observations were made, for his cooperation and Mr G. Wiseman and Mr T. Peckham, NSW Agriculture, Dubbo, for assistance with field sampling.

References

ANON. 1951. *The Queensland agricultural and pastoral handbook.* Volume 3, Insect pests and diseases of plants. Second edition. Government Printer, Brisbane: 560 pp.

CASIMIR, M. and EDGE, V.E. 1979. The development and impact of a control campaign against *Austracris guttulosa* in New South Wales. *Pans.* 25: 223-236.

COPR. 1982. *The locust and grasshopper agricultural manual.* Centre for Overseas Pest Research, London: 690 pp.

DODD, A.P. 1913. Australian Hymenoptera Proctotrypoidea No. 1. *Transactions of the Royal Society of South Australia* **37:** 130-181.

ELDER, R. 1989. Laboratory studies on the life history of *Nomadacris guttulosa* (Walker) (Orthoptera: Acrididae). *Journal of the Australian Entomological Society* **28:** 247-253.

ELDER, R. 1991. Laboratory studies of environmental factors affecting sexual maturation in *Nomadacris guttulosa* (Walker) (Orthoptera: Acrididae). *Journal of the Australian Entomological Society* **30:** 169-181.

FARROW, R.A. 1977. Maturation and fecundity of the spur-throated locust *Austracris guttulosa* Walker, in New South Wales during the 1974/75 plague. *Journal of the Australian Entomological Society* **16:** 27-39.

HELY, P.C., PASFIELD, G. and GELLATLEY, J.G. 1982. *Insect pests of fruit and vegetables in NSW.* Inkata Press, Melbourne, 312 pp.

KEY, K.H.L. 1970. Orthoptera. In: CSIRO (Ed.), *The Insects of Australia.* pp 323-347. Melbourne University Press, Melbourne.

RAJAKULENDRAN, S.V. 1990. A report on the incidence of *Valanga irregularis* as a pest of orange trees in an orchard in the Coonamble area and the results of chemical control trials. Unpublished Technical Report (A8.23), NSW Agriculture, Rydalmere: 7pp.

SJÖSTEDT, Y. 1932. Neue Acridiodea aus dem Museum in Canberra (The Federal Capital Territory of Australia) mit einer Revision der Gattuna *Chortoicetes* (Orth. Trux.). *Ark. Zool.* (A). **23:** 15 pp.

UVAROV, B. 1966. *Grasshoppers and locusts.* Cambridge University Press, Cambridge: 481pp.

WHITE, M.J.D. 1968. A gynandromorph grasshopper produced by double fertilization. *Australian Journal of Zoology* **16:** 101-109.